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APPROXIMATE METHOD OF CALCULATING THE TEMPERATURE STEADY STATE OF WATER-PERMEABLE DAMS

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In permafrost areas, in addition to water im permeable dams, use is made of water permeable ones. The thermal conditions of these dams have been fairly studied under the conditions of the planar problem. On the basis of the functions available for determining the temperature steady state of water-permeable dams, this paper proposes dependencies, utilizing N.K. Girinskiy's hydro dynamic functions.

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In permafrost areas, in addition to water impermeable dams, use is made of water-permeable ones. The thermal conditions of these dams have been fairly widely studied under the conditions of the planar problem.

On the basis of the functions available for determining the temperature steady state of water-permeable dams, this paper proposes dependencies, utilizing N. K. Girinskiy's hydrodynamic functions [4]:

Specific flow rate potential φ_g m^3/day

and current function ψ_{g_o} m^3/day

and it compares the calculation results obtained by a known method [3] with the results of calculations performed in accordance with the proposed functions.

We examine a dam made of homogeneous isotropic ground sitting on a layer of the same type of ground as in the body of the dam, which is underlaid by a water confining stratum. The water temperature in the reservoir and its level are constant, but in the lower race there is no water.

Girinskiy's filtration potential for an unconfined flow in homogeneous ground has the form [1, 4]:

$$\varphi_g = - k \frac{h^2}{2} \ m^3/\text{day} \qquad (1)$$

where: k m/day - filtration factor,

h m - depth of filtration flow.

We use Girinskiy's potential to plot a depression curve. For this purpose potentials φ_{1g} and φ_{2g} corresponding to the depths of the filtration flow in the upper race h_1 and at the drain level h_2 are designated in relative units as $\varphi_{*1g} = 1$ and $\varphi_{*2g} = 0$; then the depth of the flow in vertical lines can be obtained by the following formula, provided that the distance between the cross-sections where φ_{1g} and φ_{2g} were determined is equally divided:

$$h = \sqrt{\varphi_* (h_1^2 - h_2^2) + h_2^2} \ m \qquad (2)$$

where φ_* - the relative potential of the intermediate vertical line in fractions of the difference between the upper and lower races.

A depression curve plotted according to the values of (2) is a Dupuis parabola.

The filtration speeds at any point on the vertical line corresponding to the flow depth are equal and the vertical component is equal to zero [4].

The Girinskiy potential is used to calculate the specific flow rate of the filtration flow [2].

$$g = \frac{\varphi_{1g} - \varphi_{2g}}{L} \quad m^2/day \qquad (3)$$

where L_M is the distance between the cross-sections where φ_{1g} and φ_{2g} are determined.

The specific flow rate makes it possible to calculate the vertical speeds from the function:

$$v = \frac{g}{h} \quad m/day. \qquad (4)$$

The vertical flow is divided by surfaces which are close together and horizontal in p layers, and then the height of each layer is

$$\Delta h = \frac{h}{p} \quad . \quad M \qquad (5)$$

In expressing filtration flow in Girinskiy's hydrodynamic functions, the potential increment for two adjacent vertical lines separated by a distance Δl_φ can be represented in the following form:

$$\Delta \varphi_g = \Delta l_\varphi h v \quad m^3/day. \qquad (6)$$

Heat exchange in water-permeable ground is determined for steady state conditions by the Fourier-Kirchhof differential equation [3], which by means of the Girinskiy potential for vertical cross-sections of flow can be presented in the form:

$$h a_x \left(\frac{\partial^2 \vartheta}{\partial \varphi_g^2} + \frac{1}{q^2} \frac{\partial^2 \vartheta}{\partial \psi^2} \right) = \frac{\partial \vartheta}{\partial \varphi_g} \quad . \qquad (7)$$

At considerable filtration speeds when the convective transfer of heat along the current line predominates over conductive transfer, we can ignore the term $ha_x \frac{\partial^2\vartheta}{\partial\varphi_g^2}$ in expression (7), and then the Fourier--Kirchhof equation has the form:

$$\frac{h a_x}{\varphi^2} \frac{\partial^2 \vartheta}{\partial z^2} = \frac{\partial \vartheta}{\partial \psi_g} \quad . \tag{8}$$

In this form the equation is solved numerically in finite differences. In the vertical flow a point called the central is selected; the temperature of this point is designated as ϑ; ϑ_{upp} and ϑ_{low} indicate the temperatures of the points in front of and behind the central in the direction of the filtration flow; $\vartheta_{1\ bound}$ and $\vartheta_{2\ bound}$ show the temperatures of points above and below the central on one vertical line.

In equation (8) the derivatives in the finite differences are presented in the following form:

$$\frac{\partial \vartheta}{\partial \psi_g} \cong \frac{\vartheta - \vartheta_{upp}}{\Delta \psi_g} \quad \frac{\text{deg}\cdot\text{day}}{m^3} \tag{9}$$

$$\frac{\partial^2 \vartheta}{\partial z^2} \cong \frac{\sum_1^2 \vartheta_{bound} - 2\vartheta}{(\Delta h)^2} \quad \frac{\text{deg.}}{m^2} \quad .$$

By substituting these values into (8) with allowance for (4), (5) and (6), we obtain the formula for computing the central point temperatures:

$$\frac{\frac{h a_x}{\Delta \psi_g} \rho^2 \left(\frac{\Delta l_\varphi}{h}\right)^2 \sum_1^2 \vartheta_{bound} + \vartheta_{upp}}{1 + \frac{2 h a_x}{\Delta \psi_g} \rho^2 \left(\frac{\Delta l_\varphi}{h}\right)^2} \ \text{deg.} \quad . \tag{10}$$

There are no limitations on the application of this formula. This formula is similar to the formula of [3]:

$$\vartheta = \frac{\frac{2 a_x}{\Delta_1 \psi} \frac{1}{2} \sum_1^2 \vartheta_{lat} + \vartheta_{upp}}{1 + \frac{2 a_x}{\Delta_1 \psi}} \ \text{deg.} \quad , \tag{11}$$

which is used to determine the temperatures at the corners of the curvilinear quadrants of the hydrodynamic filtration grid. According

to (10), the temperatures are determined at the points which divide the flow depth into the accepted number of layers.

A determination of a dam's temperature state according to (10) is examined using the example of designing a dam made of homogeneous isotropic ground with a filtration factor of K = 1.7 m/day underlaid by a horizontal water confining stratum whose temperature is 0°C. Above the stratum is a layer of the same ground as is in the dam body; it is 5 m thick. The dam has tubular drainage, the upper slope of the dam is 1:2 and the lower is 1:1.5. The water temperature in the reservoir is a constant 3°C, the water depth in the upper race is h = 10 m, in the lower race there is no water.

The Girinskiy potential is used to plot a depression curve; in the flow 10 vertical lines 4.5 m apart are assumed and the speeds on the verticals are determined from (4). The results are summarized in the table (Table 1). Each of the vertical lines was divided into three equal sections, and temperatures were determined at the division points and at the extreme upper points of the vertical lines; this corresponds to the temperature state on the depression surface. In this case, upon extension of each vertical line at distance $\Delta h = \frac{h}{3}$ from the depression surface the temperature was assumed to be zero, and therefore the temperatures at points at distance Δh from the stratum surface and on the depression surface are symmetrical.

Isotherms have been plotted from the calculated temperatures (Figure 1). This same figure indicates the temperature values at the corners of the curvilinear quadrants of the hydrodynamic grid, as calculated from (11).

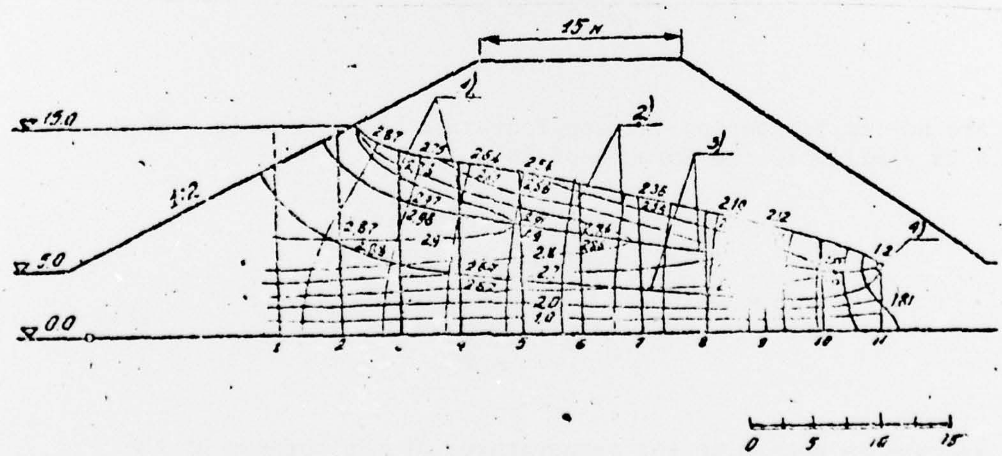

Figure 1.

A comparison indicates that the temperature values at the corresponding points of the dam cross-section coincide well; this shows that the method of approximately calculating filtration through a dam can be applied to determine the temperature steady state of water-permeable dams.

The calculated temperatures in the dam cross-section are used to determine the temperature gradients from the thawed ground, and the thawing of the frozen base during the first five years is determined with the aid of the Stefan equation.

Since the frozen ground has a temperature of zero, the gradients from the frozen ground are equal to zero; in this case thawing is determined as:

$$\Delta \xi = \Delta \xi_{tg} = \frac{\lambda_{tg}}{\gamma_f n L} \left| \deg . \vartheta_{tg} \right| \Delta t \qquad (12)$$

where: $\lambda_{tg} \frac{\text{M cal}}{\text{m} \cdot \text{deg} \cdot \text{day}}$ is the heat conductivity factor of the thawed ground;

$\left|\deg \vartheta_{tg}\right| \frac{\text{deg}}{\text{m}}$ is the modulus of the temperature gradient from the thawed ground;

$y_f \, n \, L \, \frac{\text{M cal}}{\text{m}^3}$ is the latent heat of the change in aggregate moisture state in the ground pores;

Δt day is time.

When $\lambda_{tg} = 0.0544 \frac{\text{M cal}}{\text{M} \cdot \text{day} \cdot \text{deg}}$ and $y_f \, n \, L = 27.8 \frac{\text{M cal}}{\text{m}^3}$ the intensity of thawing for a period of five years is determined (the values of $\Delta \xi$ are given in the table).

TABLE 1.

No. of vertical lines	-	2	3	4	5	6	7	8	9	I0	II
Flow depth M h	I5,0	I4,3	I3,6	I2,8	I2,I	II,I8	I0,24	9,23	8,06	6,7	5
Filtration speed m/day v	0,252	0,264	0,278	0,294	0,3I2	0,338	0,355	0,396	0,469	0,564	0,757
Thawing of base M $\Delta \xi$		2,85		2,8		2,75		2,4		2,0	I,5

Conclusion.

In making temperature calculations of water-permeable dams, in addition to precise filtration computation methods it is also possible to use an approximate method of calculation which utilizes Girinskiy's hydrodynamic functions.

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